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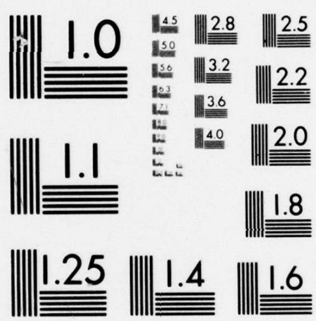

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SOUND AMPLITUDE FLUCTUATIONS DUE TO INTERNAL TIDES

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NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA. 92152

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RR GAVAZZI, CAPT, USN
Commander

HOWARD L BLOOD, PhD
Technical Director

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Large amplitude and phase fluctuations in underwater acoustic wave fields occur and are primarily due to the temporal and spatial variability of the water and its boundaries. The amplitude part of this phenomenon is investigated by obtaining simultaneously, time and space series of environmental and acoustic data from sensor arrays fixed in space, in shallow coastal water off California. The signal output from an ultrasonic source, mounted on a tripod three meters above the bottom, is monitored continuously by a hydrophone 150 meters

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away. The source radiates CW pulses at the repetition rate of one pulse per three seconds at 30 kHz. Time series of temperature from a vertical thermistor array, surface wave height, and the two horizontal components of water motion from an EM current meter are obtained. A sampling interval of three seconds was used. In continental shelf areas, the tidal force is frequently the principal driving mechanism giving rise to internal fluid oscillations of tidal period. Herein, the effect of "internal tides" upon acoustic wave propagation is examined. A low pass numerical filter was used to reject all nontidal, high-frequency components from each of the time series. Vertical, time-dependent, sound-speed profiles were determined at hourly intervals. A ray optics technique is employed to clarify the interaction mechanism and good agreement is obtained between theoretical and experimental results.

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ABSTRACT

SUMMARY

Large amplitude and phase fluctuations in underwater acoustic wave fields occur and are primarily due to the temporal and spatial variability of the water and its boundaries. The amplitude part of this phenomenon is investigated by obtaining simultaneously, time and space series of environmental and acoustic data from sensor arrays fixed in space, in shallow coastal water off California. The signal output from an ultrasonic source, mounted on a tripod three meters above the bottom, is monitored continuously by a hydrophone 150 meters away. The source radiates CW pulses at the repetition rate of one pulse per three seconds at 30 kHz. Time series of temperature from a vertical thermistor array, surface wave height, and the two horizontal components of water motion from an EM current meter are obtained. A sampling interval of three seconds was used. In continental shelf areas, the tidal force is frequently the principal driving mechanism giving rise to internal fluid oscillations of tidal period. Herein, the effect of "internal tides" upon acoustic wave propagation is examined. A low pass numerical filter was used to reject all nontidal, high-frequency components from each of the time series. Vertical, time-dependent, sound-speed profiles were determined at hourly intervals. A ray optics technique is employed to clarify the interaction mechanism and good agreement is obtained between theoretical and experimental results.

CONTENTS

INTRODUCTION

A relation exists between the fluctuations of sound and the fluctuations of sound velocity in the ocean. Changes in the sound velocity are caused by two processes: one is random, the other periodic. Random inhomogeneities in the sound velocity are caused by temperature and salinity fluctuations. These are induced by turbulent processes in the ocean. Periodic fluctuations in the sound velocity arise from internal gravity waves and related periodic oscillations of the liquid medium. Of particular interest here are internal waves of tidal period – often called "internal tides" – which frequently dominate the fluctuations of water properties.

Since sound propagation in a liquid channel is a boundary value problem, the variability in the environment will manifest itself both in the sound speed and in the boundary conditions. In the general case both the boundary conditions and the sound velocity are functions of space and time. Herein, we will confine ourselves to shallow water acoustics. Shallow water acoustics is a very important problem because nearly eight percent of all oceans and adjacent seas lie within the 200-meter depth contour. This fact assumes added significance because this band of water of variable width surrounds the continents of the globe and as such plays a fundamental role in the affairs of man.

Shallow water acoustics have continued to receive wide and intense attention for more than thirty years and results are well summarized by numerous authors. Scrimger (Ref. 1) described changes in acoustic propagation over a 100-meter distance in 3 meters of water. He finds that amplitude and phase fluctuations in the acoustic field are induced by surface roughness. Tonakanov (Ref. 2) observed similar results in a shallow water reservoir. Steinberg and Birdsall (Ref. 3) find amplitude and phase changes in the acoustic signal to be related to seasonal, diurnal, and surface-wave periodicities. Urick et al. (Ref. 4) observed acoustic signal fluctuations related to tidal and swell effects in 18 meters of water off Fort Lauderdale, Florida. Weston et al. (Ref. 5) have studied propagation and fluctuation of sound in shallow coastal waters off the British Isles. They identify at least nine fluctuation mechanisms. Their investigations extend over several years and they find amplitude and phase fluctuations with periods ranging from a year to less than a second. Finally, Wood (Ref. 6), in his model tank experiments, noted pronounced changes in the sound field produced by a change of a fraction of a millimeter in the water level caused by evaporation from the tank.

Yet in spite of this intense activity, it is not yet possible to provide quantitative and accurate predictions. The difficulty lies in the complexity of the shallow environment. Environmental parameters display complex space and time variations. All spatial and temporal scales of motion vary widely. Space scales range from molecular to oceanic dimensions and time scales range from a fraction of a second to many years. Hence, extrapolation of results obtained in a particular place and time in shallow water to other places in the world ocean will depend on the scale in question. As a general rule results for small scales

should be applicable to all oceans and seas. Results for large scales usually are strongly restricted to the locations in which they are obtained.

This paper describes some observations made in shallow water with the object of increasing the understanding of fluctuations in a limited range of conditions. The method employed is to acquire simultaneously long time series of environmental and acoustic information from arrays of sensors fixed in space.

EXPERIMENTAL SET-UP

Experimental data for this investigation were acquired in March 10-16, 1972 near the NOSC Oceanographic Tower located 1.6 kilometers offshore from Mission Beach in San Diego in water 18 meters in mean depth, LaFond (Ref. 7). The sea floor at the observation site is medium grain sand and slopes uniformly from the tower without any outstanding topographic features in the area.

A sound projector with a 12-degree beam width at the 3-dB down points was mounted at the apex of a tripod 3 meters above the ocean bottom with its beam axis parallel to the sea surface. The sound source radiates CW pulses sequentially at 30 kHz, 45 kHz and 60 kHz at a repetition rate of one pulse per second. The acoustic source level at one meter is constant at 100 dB/1 μbar for the three frequencies. Two hydrophones are colinearly placed with the projector at 2 and 150 meters from the projector. The hydrophone signal outputs are cabled to the NOSC Oceanographic Tower where the acoustic signals are digitally recorded on magnetic tape. The hydrophone at 2 meters is used to monitor the projector signal output and to help in determining the travel time of the pulses between the two hydrophones. Environmental information was obtained from a vertical thermistor array, a two-component EM current meter and a Baylor (Ref. 8) wave staff. All environmental sensors were placed close to the 150-meter hydrophone near the tower. A total of 11 thermistors spaced 1.8 meters apart were used. The thermistors had a time constant of 6 seconds and yielded a relative accuracy of $\pm 0.03°C$. The Baylor wave staff is a wave profile recording system which measures instantaneous surface elevation as a function of time. Wave height measurements are accurate within one percent of actual height. The two horizontal components of water motion were obtained at mid-depth with an EM current meter (Olson, Ref. 9). The threshold velocity for this instrument is limited by the electronic noise level which for the present configuration has an rms value of less than ± 0.015 cm/sec. The frequency response is from dc to an upper frequency limit of 0.6 Hz.

Travel time for the acoustic pulse to traverse the distance between the two hydrophones was also recorded. A total of 17 channels of signal output was fed into a digital tape recorder with a 3-second sampling period.

ANALYSIS OF DATA AND DISCUSSION

In this paper an ensemble of time series of 6-day duration for the environmental and the 30-kHz acoustic signal is examined. Amplitude fluctuations with periods of a few seconds to tidal periods were observed for the acoustic as well as the environmental time series. However, only the effect of the tidal oscillation will be considered herein.

The total mean temperature variation between the surface and the bottom of the water column is about 2.5°C. This temperature change corresponds to a maximum sound speed change of 10 m/sec. The time series from each sensor was subjected to a low pass numerical filtering process with a time constant of one hour. A sequential display of the filtered time series revealed oscillations of tidal period with the same wave-like behavior at all depths. The filtered time series display shown in Fig. 1 clearly shows the internal tide fluctuations. The fluctuations have maximum amplitude in the middle of the water column and minimum near the surface and the bottom. The temperature fluctuations at fixed depths are indicative of the sound speed changes at these depths. For a temperature change there must be a corresponding vertical movement and/or horizontal movement of the water to produce this change. From the data shown in Fig. 1, three isotherms for 12.4°C, 13°C, and 13.6°C were calculated. These are shown in Fig. 2. Internal tides having amplitudes of about 8 meters are clearly visible.

In Fig. 3 a selected number of temperature traces are shown at the top. Next shown are the two horizontal components of current followed by the surface tide, the acoustic signal, and the travel time. The significance of this figure is that the fluctuations shown for the thermal and current structure, as well as for the acoustic signal and the travel time, are fully controlled by the surface tide. The thermal and current fluctuations are nearly in phase with the surface tide. The acoustic signal and the travel time, however, are out of phase. In general, there is a tendency for the acoustic signal to have a maximum amplitude when the tide is low and minimum when the tide is high. The travel time shows a similar behavior. For most of the time series shown in Fig. 3, the acoustic signal fluctuates by approximately 5 dB and for the last 30 hours fluctuations as high as 10 dB are noted. More dramatic fluctuations have been obtained for the summer season when the thermocline is fully developed but these results have not been fully processed and will not be presented herein. There are, of course, fluctuations of internal wave and surface swell frequencies not shown here. In terms of fluctuations of internal wave periods the acoustic signal is most stable at high tide and fluctuates most at low tide. This is because during high tide the thermocline is nearly at mid-depths and the principal acoustic rays do not intercept the thermocline which is the center of maximum internal wave activity. During low tide, however, the thermocline is closer to the bottom and the acoustic rays pass through the thermocline.

Since the thermocline undergoes vertical displacement with tidal period, raised at high tide and lowered at low tide, the travel time will be a maximum at low tide and minimum at high tide. At high tide the thermocline is near the surface and the acoustic pulse will travel through a medium with a relatively low sound velocity; whereas at low tide, the thermocline is lowered and the acoustic pulse will travel through a medium with a relatively high sound velocity.

Although fluctuations from a few seconds to transtidal have been observed herein, we will stress fluctuations due primarily to internal tides.

From the acoustic propagation point of view, the tidal effect plays a dual role in a stratified fluid. It changes the water depth and induces internal tides and related internal oscillations which then change the vertical temperature and salinity profiles. This, in turn, changes the vertical sound speed profiles.

Bucker's (Ref. 10) ray sweep-out method was used to calculate the ray intensity field at the receiver. In this method all ray arrivals are found and the total ray intensity field at the receiver is determined during a single sweep-out of the source beam pattern. Herein, surface and bottom boundary losses and volume absorption are neglected and only an incoherent ray sum is obtained.

An hourly mean velocity profile was obtained for the entire time series resulting in 140 velocity profiles. This takes care of the tidal effect on the velocity versus depth profile. At first, the tidal effect on water depth was neglected, and the sound field and travel time were determined for the entire time series. Good comparison is obtained between the computed and observed acoustic signal and travel time. Although the comparison between the two sets of data is not exact, tidal related changes are found in the calculated sound field and travel time. Next, the tidal effect on the water depth was taken into account and a new computation for the sound field and travel time was made. The results for this computation are shown in Fig. 4. There is improvement in the comparison between computed and observed travel time. The depth changing effect of the tide on travel time is to accentuate the maxima and the minima. That is, during high tide there should be a slight increase in the travel time and during low tide there should be a slight decrease. No decisive improvement is gained for the acoustic signal in the comparison between the observed and computed values.

CONCLUSIONS

Although the problem of acoustic fluctuations in the ocean is of considerable importance to both oceanographers and acousticians, it has not received adequate treatment. Herein, interest was primarily focused on the relation between the internal wave variations on the propagation characteristics of the ocean and the fluctuations of the acoustic signal transmitted through it. Analysis of long time series of environmental and acoustic variables shows that there are significant fluctuations of tidal period present in both variables. Internal wave fluctuations of tidal period are generated by the surface tide. It has been shown that the principal characteristics of the tidal effect upon the acoustic field can be accounted with a simple ray model.

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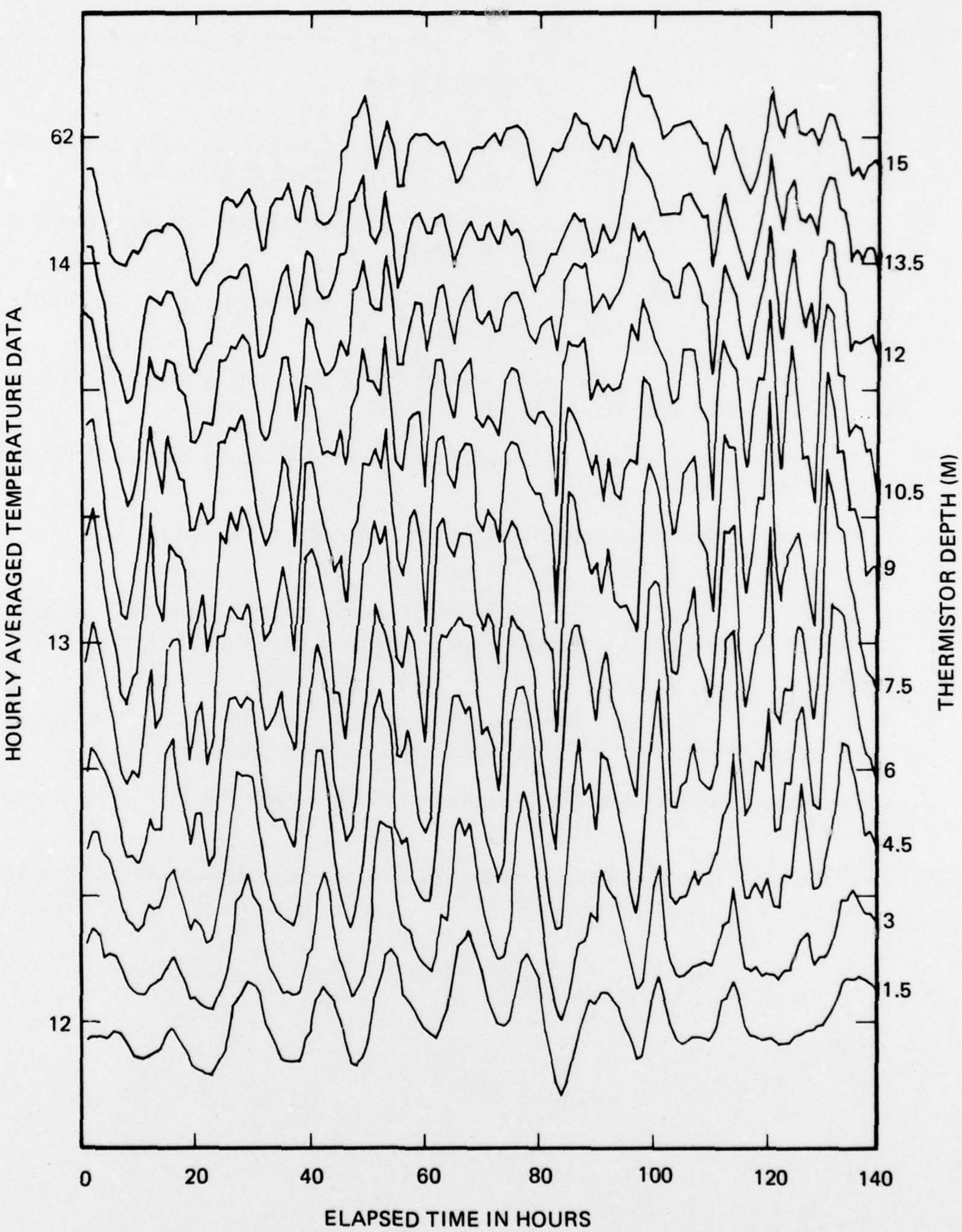

Figure 1. Temperature time series obtained from an eleven thermistor vertical array and smoothed by a one hour equally spaced running mean. The output from the thermistor near the surface is not included herein. The thermistor depths shown at the right hand side are with respect to the bottom. The scale on the ordinate is in °C.

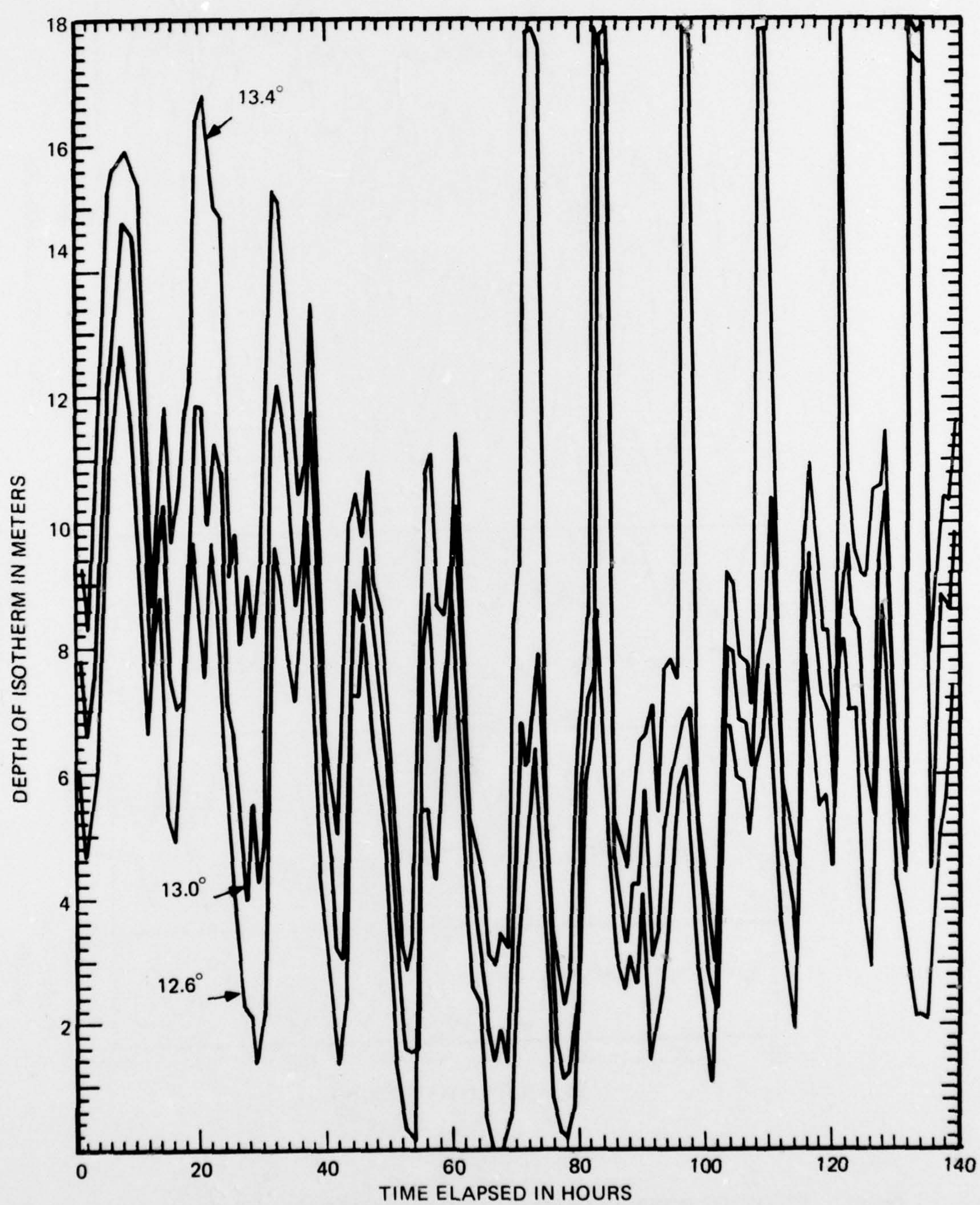

Figure 2. Three isotherms at 12.6°C, 13.0°C and 13.4°C.

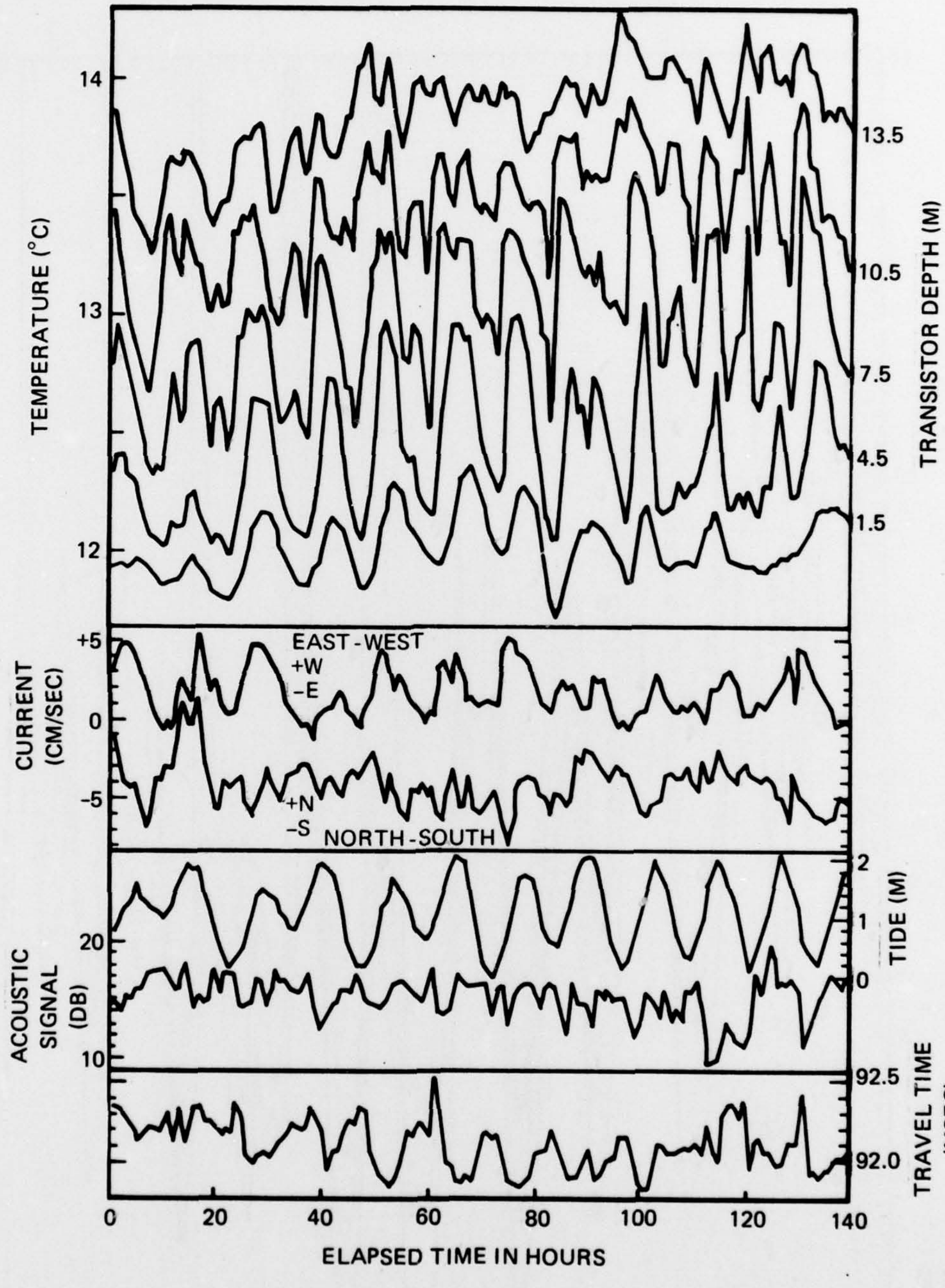

Figure 3. Smoothed time series (from top to bottom) for temperature, current, surface tide, acoustic signal, and travel time. For the current time series +W means that the current is toward the west, -E toward the east, +N toward the north and -S toward the south.

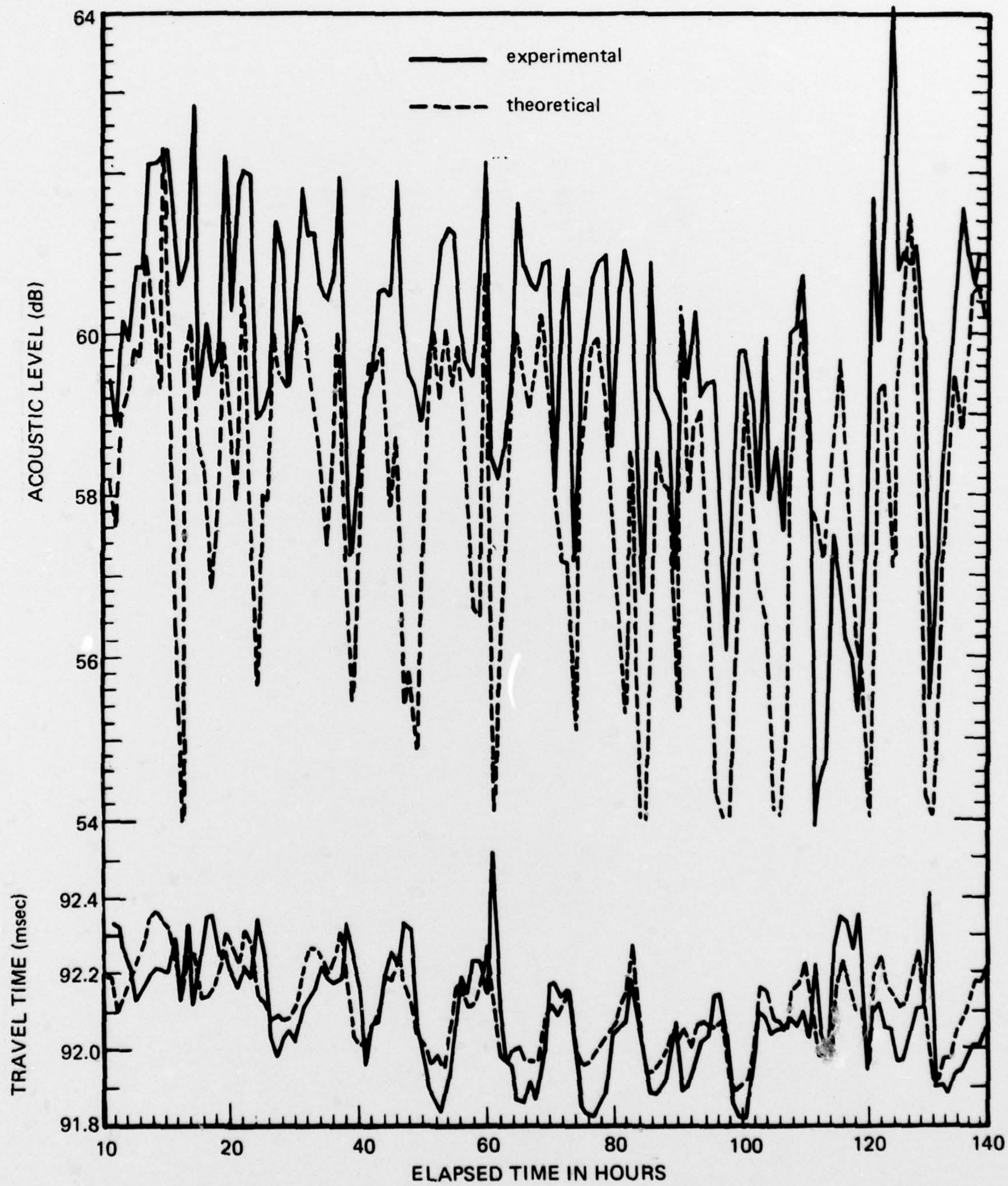

Figure 4. Comparison between experimental and theoretical results for acoustic signal and travel time taking into account the change in depth due to surface tide.